Muon g-2 WBS 476.02.02 – Target Station

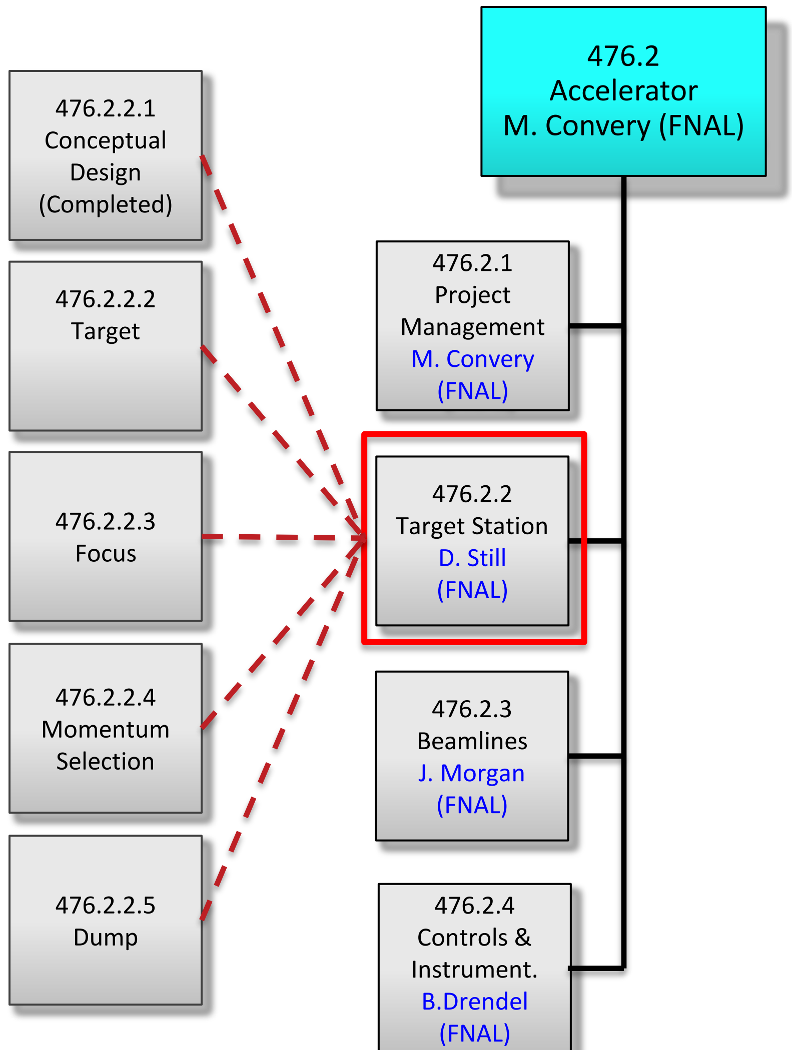
Muon g-2 DOE CD-2/3 Review
July 29-31, 2014

D. Still
Muon g-2 L3 Manager

Outline

- WBS L3 Organization
- WBS L3 Scope of this system
- Requirements
- Design
- Alternatives Considered and Value Engineering
- Risk Analysis
- ES&H
- Quality Control and Assurance
- Schedule Summary
- Cost Summary
- Summary

WBS 476.2.2


476.2
Accelerator
M. Convery (FNAL)
476.2.1
Project
Management
M. Convery
(FNAL)
476.2.2
Target Station
D. Still
(FNAL)
476.2.3
Beamlines
J. Morgan
(FNAL)
476.2.4
Controls &
Instrument.
B.Drendel
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Conceptual
Design
(Completed)
476.2.2.2
Target
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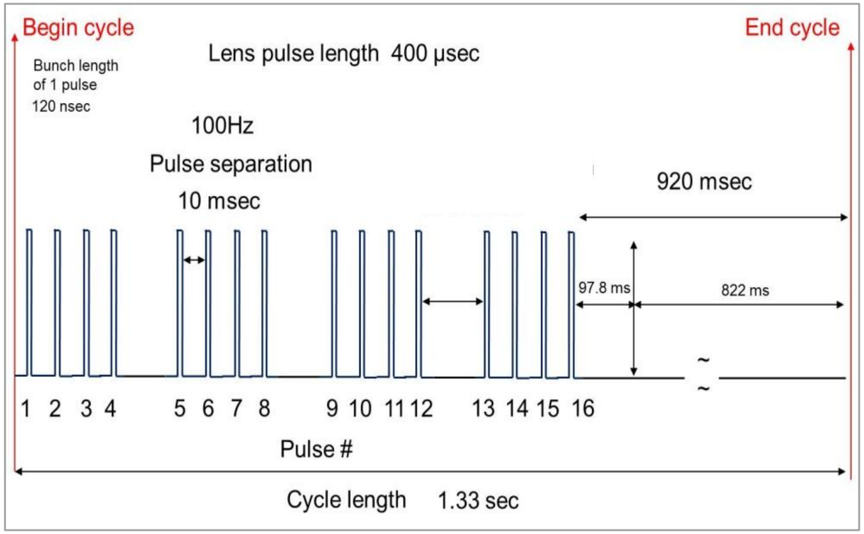
Focus
476.2.2.4
Momentum
Selection
476.2.2.5
Dump

Target Station Scope

- A target station that is capable of a suitable pion production rate based on g-2 pulse repetition rate and the re-use of the AP0 target hall including
  - Target
  - Lithium lens and pulsed power supply
  - Momentum selection magnet and pulsed power supply
  - Beam dump for off-momentum secondaries

Target Station Requirements

- Accept 8-GeV protons on target and pulse the lens and momentum-selection magnet at 12 Hz average, with 100 Hz bursts



g-2 average 12Hz pulse scenario

- Produce and capture 3.1 GeV/c secondary π^+
  - Approximately 3×10^7 π^+ with $|dp/p|<2\%$ per 10^{12} POT required for desired muon yield to storage ring
  - Integrate 4×10^{20} protons on target to reach expected experimental performance.

Target Station Design

- The design for the target station is based on reusing and repurposing the antiproton production target station used for the collider program.

- 25+ years of experience and modifications /improvements

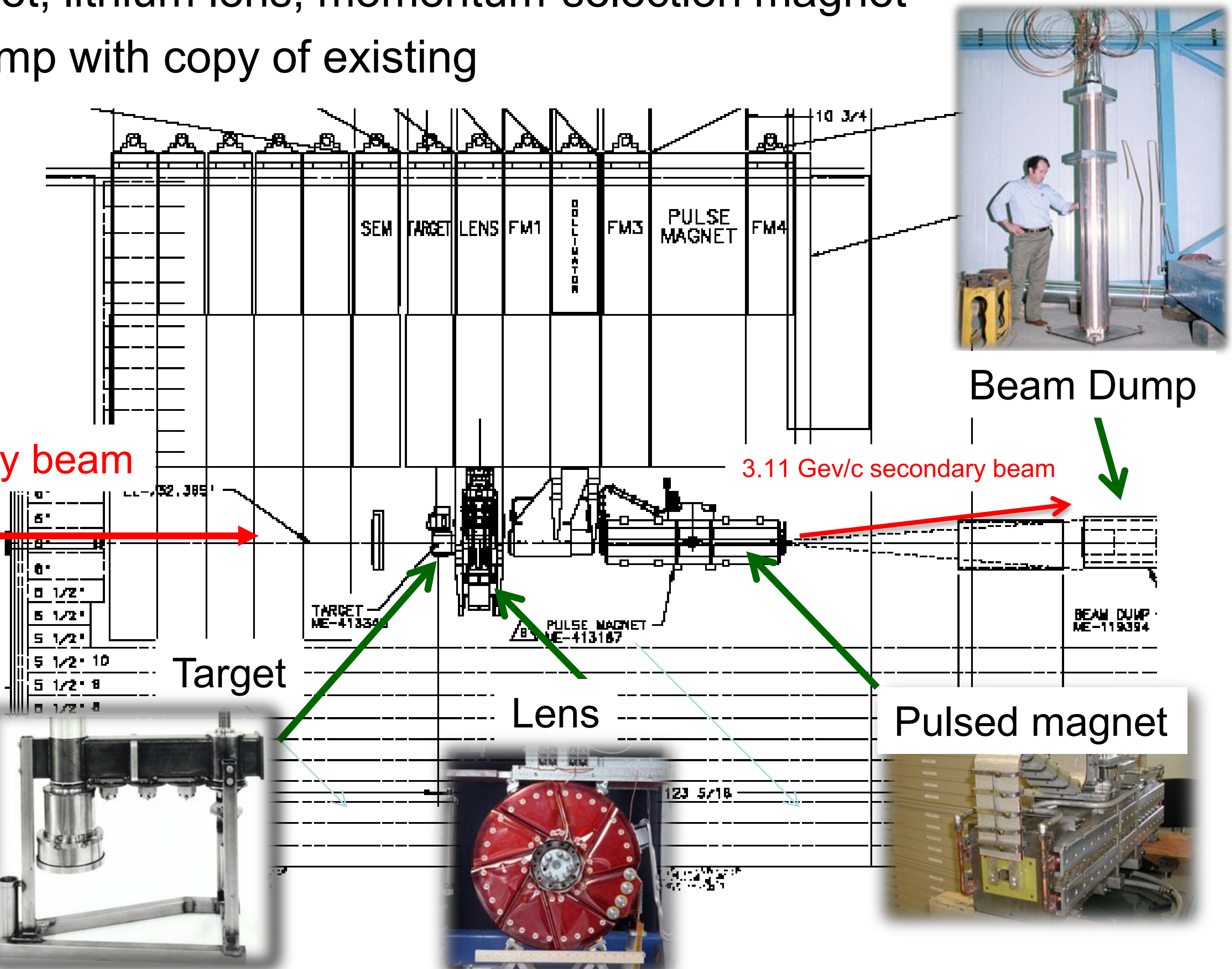
- Re-use will include:
  - Target tunnel Vault & Vault components
  - Radioactive remote handling area & 25 years of good practice procedures
  - Lens and PMAG pulse testing area
  - Closed loop radioactive water cooling systems
  - Pulsed power supplies for testing
  - Controls and timing
  - Radioactive storage vault

(AP0 Target Station Building)

(AP0 Target Station Building – Showing Target Vault area and pulse testing area)

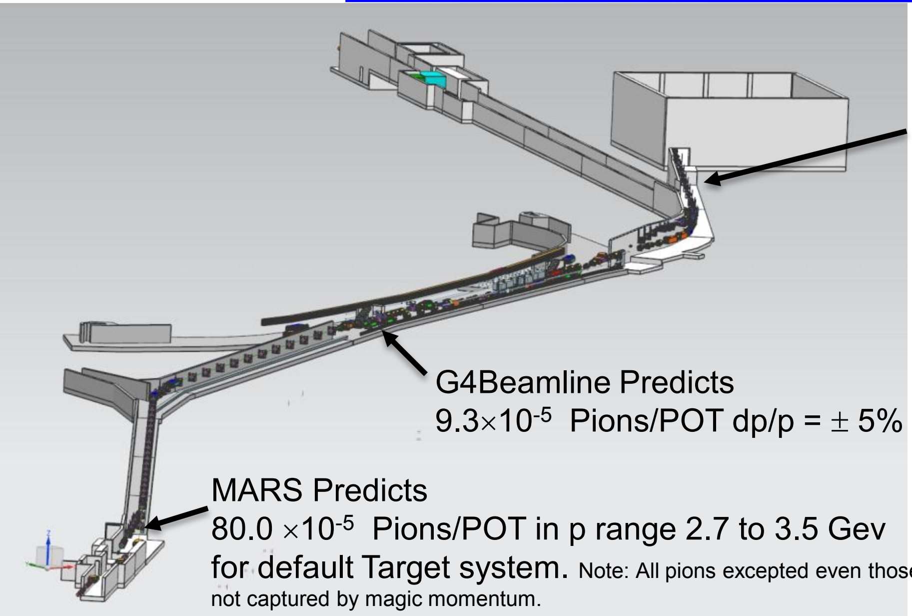
Target System Design (cont)

- Re-use target, lithium lens, momentum-selection magnet
- Replace dump with copy of existing
- New pulsed power supplies



Yield – Simulations & Measurements

Muon g-2

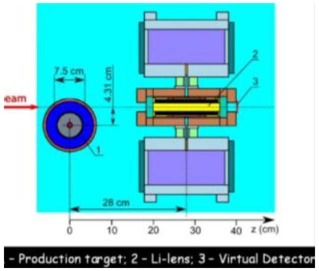


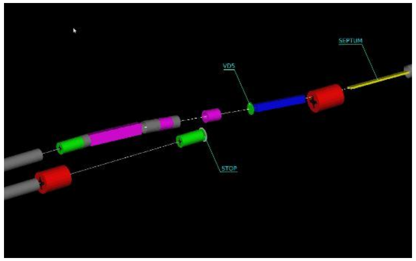
G4Beamline Predicts
After 5 Turns in the DR & before the inflector
1.5×10^{-7} Muons/POT or 1.5×10^{5} per fill (1×10^{12} POT)
dp/p = $\pm$ 0.5%

G4Beamline Predicts
9.3×10^{-5} Pions/POT dp/p = $\pm$ 5%

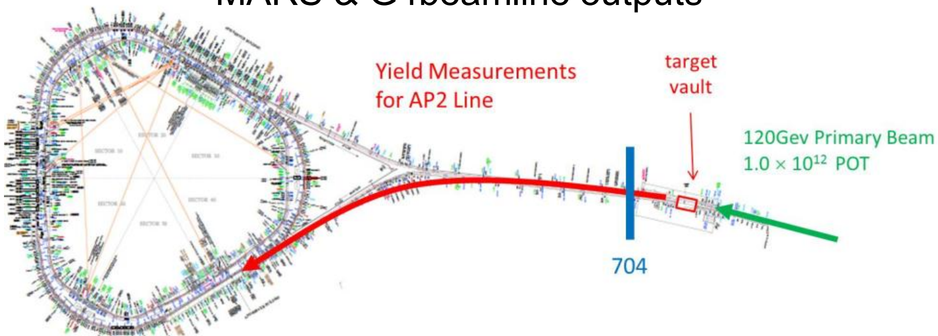
MARS Predicts
80.0×10^{-5} Pions/POT in p range 2.7 to 3.5 Gev for default Target system. Note: All pions excepted even those not captured by magic momentum.

(V. Tishchenko, "MARS & G4beamline Simulations:" GM2-doc-1668)





MARS & G4beamline outputs



(V. Tishchenko, "MARS & G4beamline Simulations for AP2 Beamline" GM2-doc-1885)

- MARS was used to predict yield from the Target.
- MARS yield was placed into G4beamline to predict number of muons at the end of the M5 beamline.
- Predicted pion target yield is on par with number of muons required by the experiment (~6000). Note: There is a 6-10% transmission eff. through the Muon Ring inflector resulting in 9000-15000 muons.

- Conducted Yield Beam Studies in 2012 & 2014.
- Concluded that simulations were in good agreement with measurements.
- Predicted 9.3×10^{8} particles @ 704 off the target.
- Measured 8.0×10^{8} particles for 1.0×10^{12} POT.
- 16% difference in predicted vs. measured.

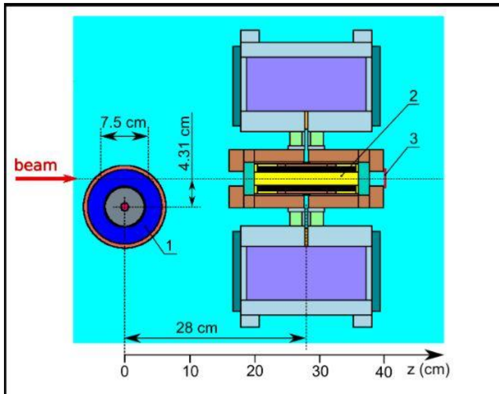
Target System Optimization

Muon g-2

(V. Tishchenko, “Update of Li-lens Optimization” GM2-doc-1789)

MARS simulations were used to optimize the target system.

Optimizing parameters for target spot size, target to lens focal length and lens gradient it is estimated that up to a 30% gain in pion production could be achieved.



1 – Production target; 2 – Li-lens; 3 – Virtual Detector

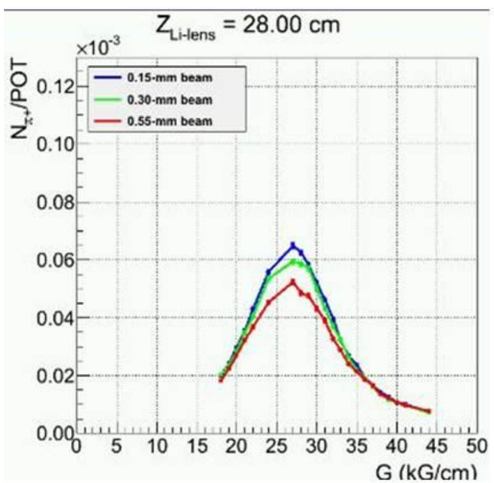
incident proton beam:

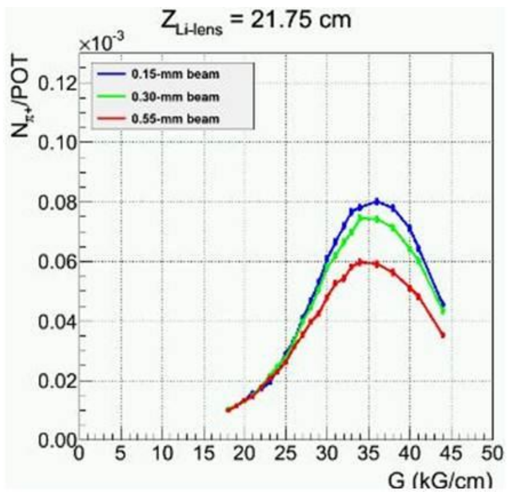
Name	σ_x, mm	$\sigma_{x'}$, mrad	σ_y, mm	$\sigma_{y'}$, mrad
0.15-mm	0.15	0.64	0.15	0.64
0.30-mm	0.30	0.50	0.30	0.50
0.55-mm	0.55	0.38	0.55	0.38

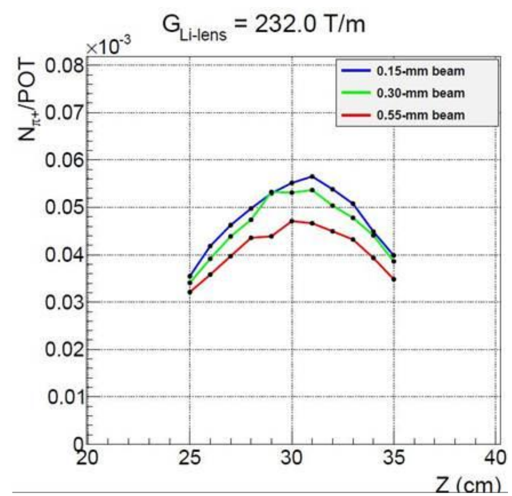
Todo: adjust $\sigma_{x'}, \sigma_{y'}$ to $\varepsilon = 0.3\pi$ emittance.

MARS model was provided by Sergei Striganov

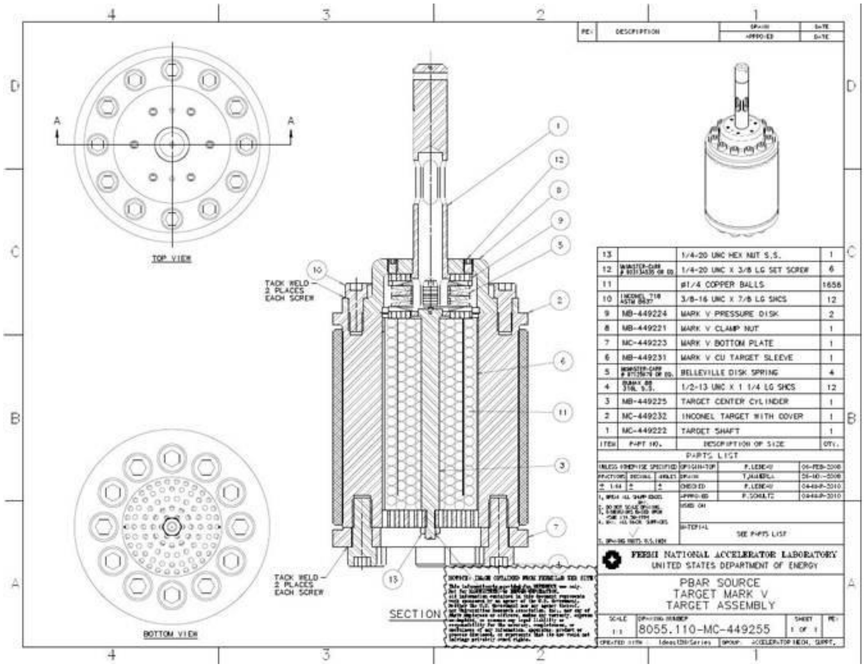
- Default (CDR) geometry as shown on the cartoon
  - Proton beam:
    - $\sigma_x = \sigma_y = 0.55$ mm
  - Li-lens current: 115 kA (230 T/m field gradient)
- Min. Li-lens – target distance: 21.75 cm
- Max. Li-lens – target distance: 33.4 cm
- Max. Li-lens field gradient: G = 301 T/m
- Baseline design field gradient: G = 232 T/m

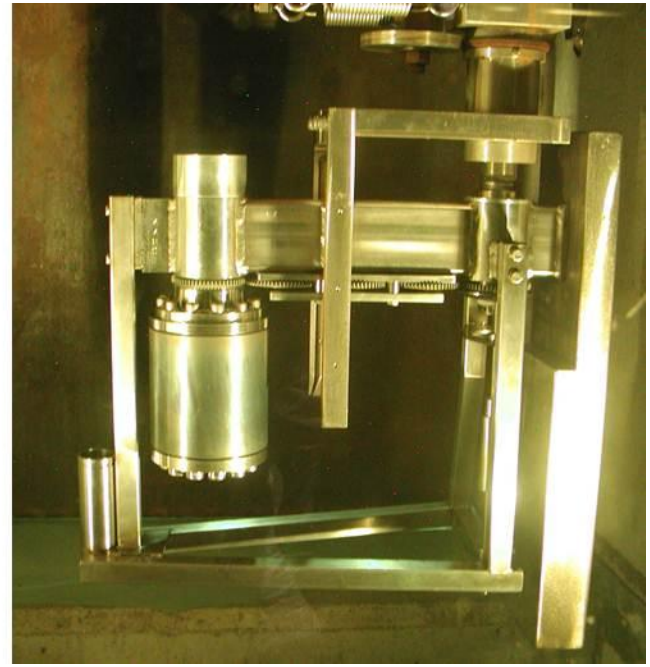






g-2 Target





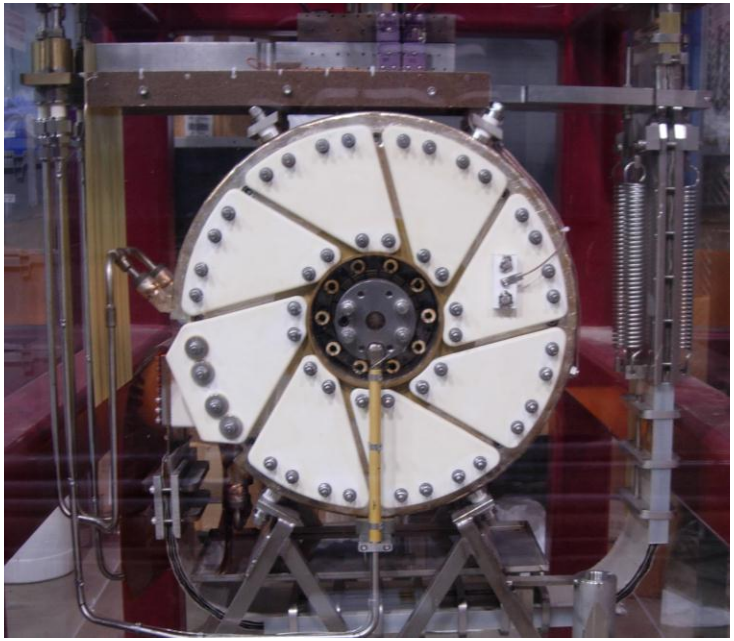
- Target is solid Inconel 600 core with 5.715 cm radius. Typical chord length of 8.37cm.
- Target center is bored out for pressurize air to pass for internal cooling.
- It has a Be outer cover to keep it from sputtering Inconel onto Lens.
- Incorporates target motion control for x-y-z positioning & rotational motion 1turn/45sec

- Plan is to use the presently Installed target

Lithium Lens

Lens operation	Pulse width (μsec)	Peak Current (kA)	Gradient (T/m)	Pulses per day	Rep Rate (Hz)
Antiproton production	400	450	670	38880	.45
g-2 pion production	400	155	232	1036800	12

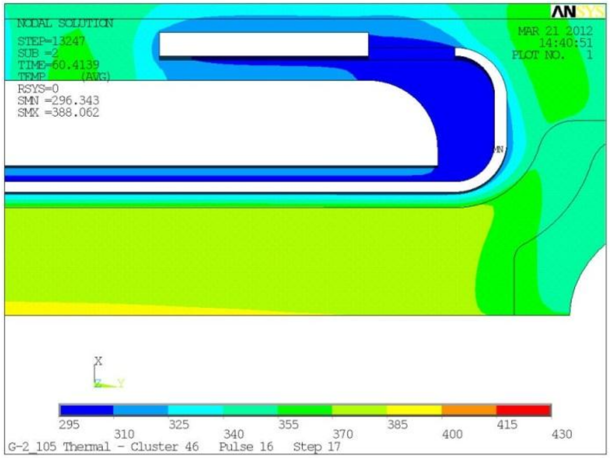
- The lens is a 1 cm radius x 15 cm long lithium cylinder that carries at large current to provide large focusing effect to divergent particles off target.
- The lens and transformer are water cooled.
- The lens will be re-used as is.
- Initially reusing the Lithium Lens was one of the biggest concerns. Pulsing at the g-2 rep rate means 1M/day where lifetimes of a lens in collider was on the order of 5-10M pulses.

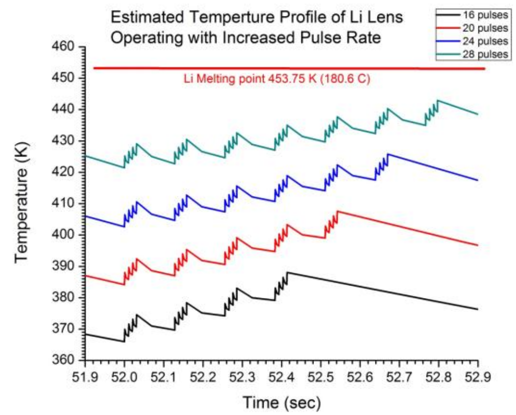


Lithium Lens and transformer

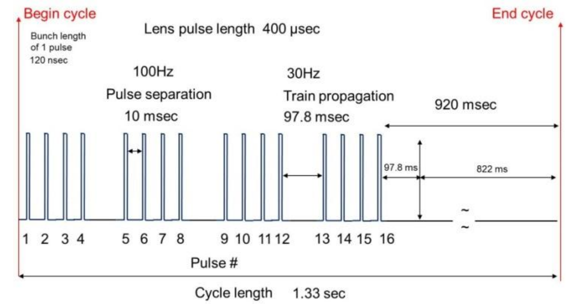
- There are currently 2 new spares

Lens-Target System Concerns





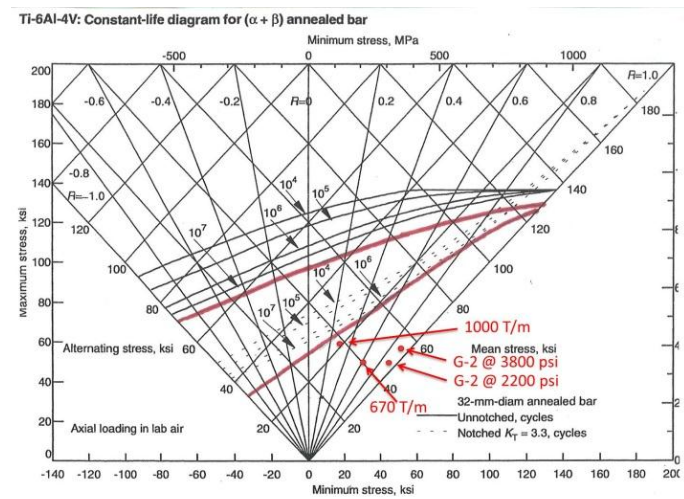
ANSYS thermal model – Temperatures for 12Hz well below Li melting point



Lens required pulse scheme

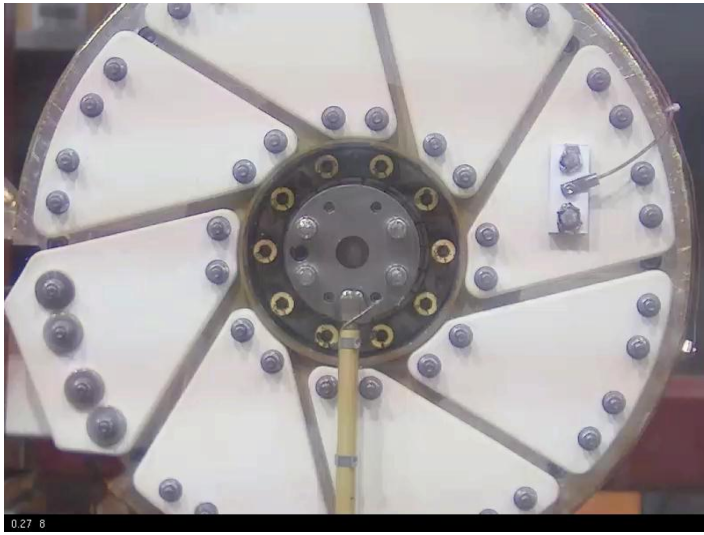
Concerns with the Lens pulsing with the g-2 repetition rate.

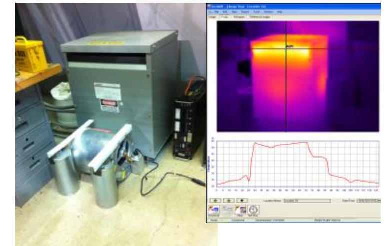
R. Schultz conclude after a full ANSYS thermal & fatigue analysis that the Lens should be able to operate reliably at 12Hz.



Lens ANSYS Fatigue analysis. Lens is under fatigue limit at 12Hz

Lens 12 Hz Pulse Testing

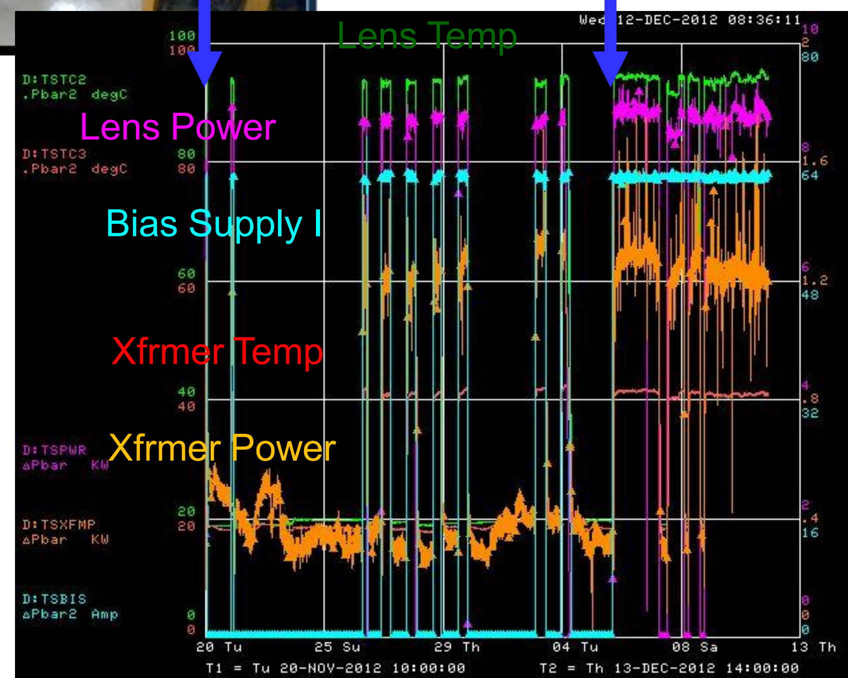




July 6, 2012 - Assess/modify firing circuit of Lens test power supply to run at 12Hz.

Nov 20,2012

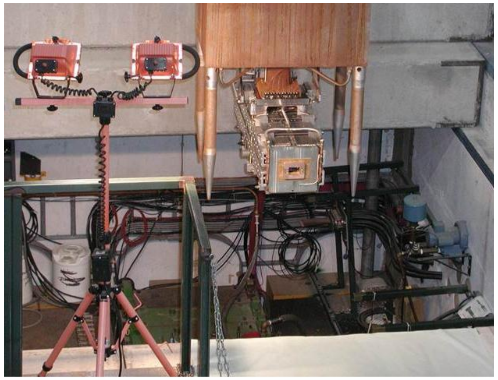
Dec 6,2012

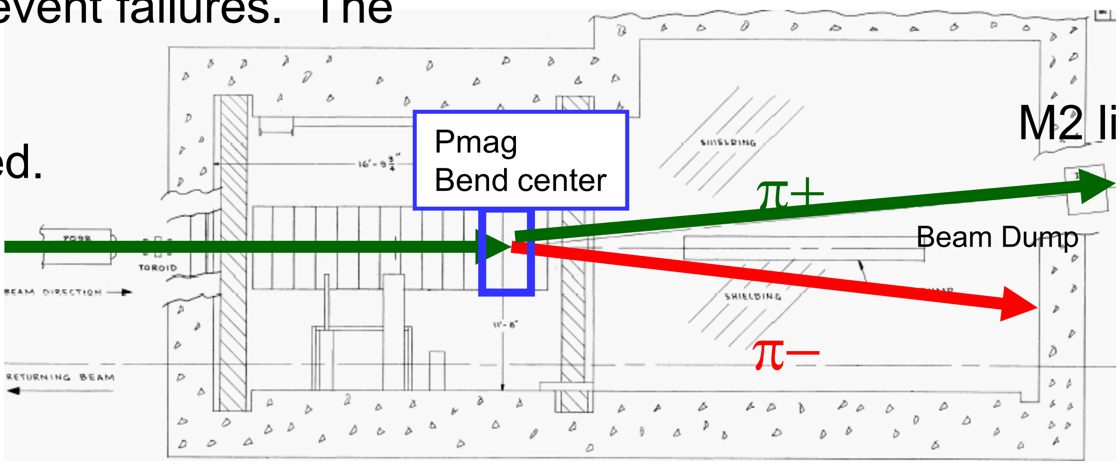


- On Nov 20, 2012 lens running at 12Hz at 19.25kA (g-2 operating current)
- Since then, attempting to accumulate pulses. Want ~ 100 M pulses @ 1M/ day
- Pulses to date = 80M at 19.25kA (155kA secondary peak) at 12Hz for 3 months without a lens problem!

Pulsed Magnet (PMAG)

- PMAG will select 3.11 Gev/c positive particles $\pi+$
- Bends particles 3° into the M2 line
- Operates at 0.53T and is 1.07 m long.
- It is a single turn magnet that has incorporated rad hard hardware (ceramic insulators between magnet steel, single conductor bars, Torlon insulted bolts)
- PMAG is water cooled and has 3 spares.
- A collimator was installed upstream of PMAG to help shield it from radiation to prevent failures. The collimator will be re-used.
- PMAG magnet will be re-used.





Lens & PMAG Power Supply Requirements

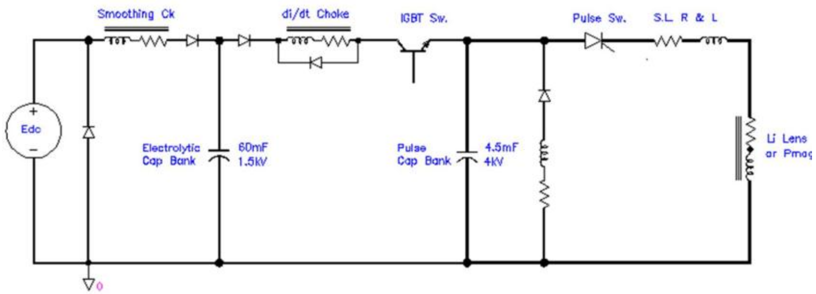
Muon g-2

g-2 LENS POWER SUPPLY SPECIFICATION	g-2 PMAG POWER SUPPLY SPECIFICATION
MAGNET:	**MAGNET:**
Type: Transformer-Lens	Type: 1-turn Magnet
Location: AP0	Location: AP0
Inductance: 2.83 uH, from transformer primary.	Inductance: 2.539 uH
Resistance: 0.0145 ohms	Resistance: 0.003387 ohms
CURRENT PROGRAM	**CURRENT PROGRAM**
Pulsed – ½ sinewave:	Pulsed – ½ sinewave:
Peak Nominal Current: 20 kamp	Peak Nominal Current: 15.3 kamp
Peak Maximum Current: 25 kamp	Peak Maximum Current: 18 kamp
Pulse base: 400 usec (same as existing lens system)	Pulse base: 355 usec (same as existing mag system)
Maximum rep rate: 100 Hz	Maximum rep rate: 100 Hz
Maximum average rep rate:	Maximum average rep rate:
nominal 12 Hz,	nominal 12 Hz,
maximum 18 Hz.	maximum 18 Hz.
REGULATION:	**REGULATION:**
Drift and Stability : +/- 0.1% of maximum	Drift and Stability: +/- 0.1% of maximum
AC input: 480 VAC, 3phase	AC input: 480 VAC, 3phase
Cooling: Air and/or LCW	Cooling: Air and/or LCW
Controls: Accelerator timing system	Controls: Accelerator timing system
POWER SUPPLY LOCATION: AP0	POWER SUPPLY LOCATION: AP0
must fit within present PS footprint.	must fit within present PS footprint.

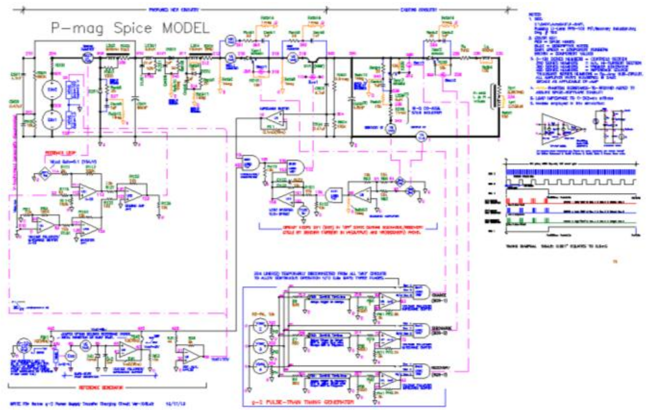
Lens & PMAG Power Supply Modifications

Muon g-2

Charge Transfer Method



(K.Bourkland/D. Wolff)



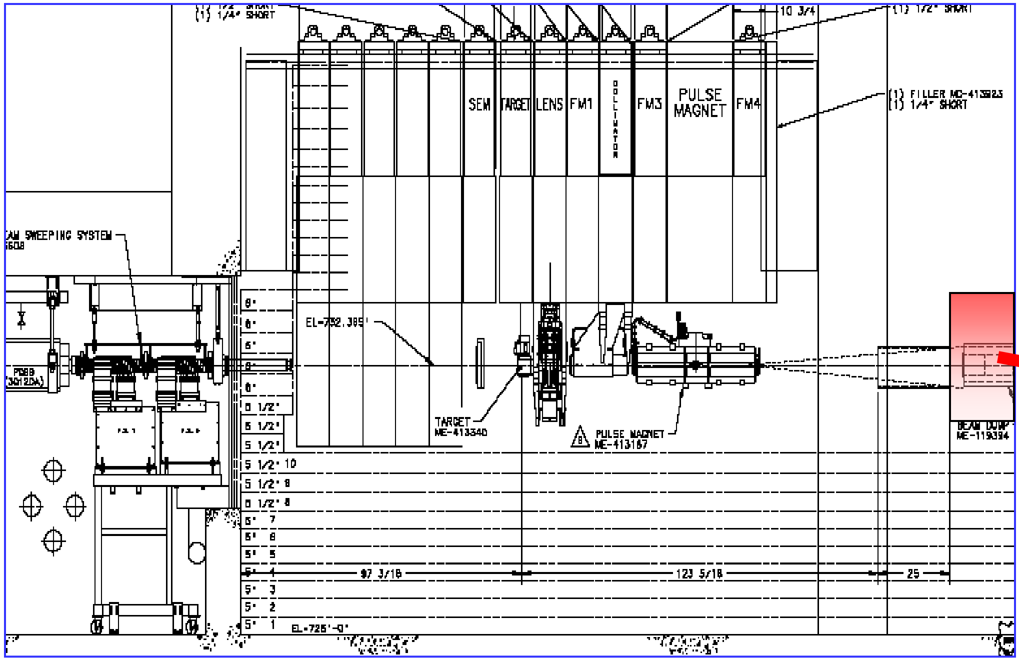
Lens spice model

Present Lens & PMAG Power Supply

D. Wolff, “Lithium Lens Power Supply Modifications”, GM2-doc-169
K. Bourkland, “Lens & PMAG Designs”, GM2-doc-1706
K. Bourkland, “Lens & PMAG Power Supply Controls Requirements”, GM2-doc-2027

- Both the Lens & PMAG power supply will need to change to accomplish 12Hz rate.
- Both power supplies will have the same design - Charge transfer method.
- Both power supplies will modify the existing power supply.
- Power supply controls will be upgraded.
- All load cables and load connections will be reused.
- The current power enclosures will need to be expanded.
- Currently have a fully developed spice model, component designs and layout.

Current Beam Dump



- Target beam dump absorbs particles that are not momentum selected by PMAG.
- Dump consists of a water cooled graphite & Aluminum core.
- It is 16 cm in diameter and 2m in length.
- Dump capacity is 80kW.
- The current dump developed an irreparable water leak at the end of the collider run.

Beam Dump Plans

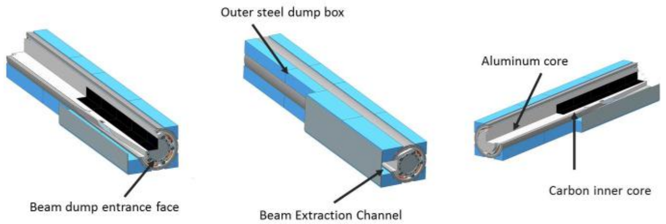
Fig 1.17: (left) Front face of the beam dump as taken in 2003. (Right) Looking down on the top of the dump plug below the surface of the shielding blocks .

- Plan is to build an upgraded copy of the current 80kW dump for replacement.
- MARS simulations have been completed to determine radioactive dose rates for planning replacement to mitigate radioactive contamination and worker exposure.
- Plan is to build a coffin and place the current beam dump in for transportation and storage onsite at TSB.

Table 1: A summary of partial peak radiation dose rates in mrem/hr at contact with various surfaces of the beam dump and beam dump plug are given in the Table. The peak dose rates are taken from the MARS histogram results for each irradiation/cooling period. The upper limit of peak dose rate is indicated in the sum column.

Histogram number	Histogram name	2001	2004	2007	2011	2014	sum
701	beam_rt_dump_core	32	230	1,300	23,000	24	24,586
702	beam_left_dump_core	25	180	1,100	18,000	19	19,324
703	bottom_of_dump_core	25	200	1,200	20,000	21	21,446
704	top_locator_plate	13	74	540	12,000	13	12,640
705	upstream_core	1,300	15,000	61,000	350,000	56	427,356
706	downstream_core	1,100	12,000	52,000	290,000	43	355,143
707	right_side_plug	4.9	28	200	4,700	5.3	4,938
708	left_side_plug	4.2	24	180	4,100	4.6	4,313
709	US_lower_plug_face	0.63	3.5	25	560	0.61	590
710	DS_lower_plug_face	5.9	33	240	5,200	5.9	5,485

A. Leveling, "Pbar Target Vault Beam Dump Residual Activity", Fermilab Doc GM2-doc-1691.



Target Station Risks

Registry contains 1 risk:

- Removal of the dump takes longer than estimated
  - Small impact on project

Registry contains 3 risks removed where a Threat is Avoided or the Opportunity Realized:

- Lens is not able to pulse at g-2 rep rate
  - ANSYS analysis has determined that the lens should be able to handle the fatigue at the g-2 rep rate
  - Pulse testing (80M pulses over 3 months) has confirmed that the lens can operate at 12Hz at full gradient
  - At this point the risk is low
- Default target found to not produce the desired pion yield
  - Run longer or build alternate target (~10% gain)
- Opportunity that yard transformer to support lens power supply is not needed ($100k)
  - Transformer no longer part of the design after Preliminary Design phase.

Target Station ESH&Q

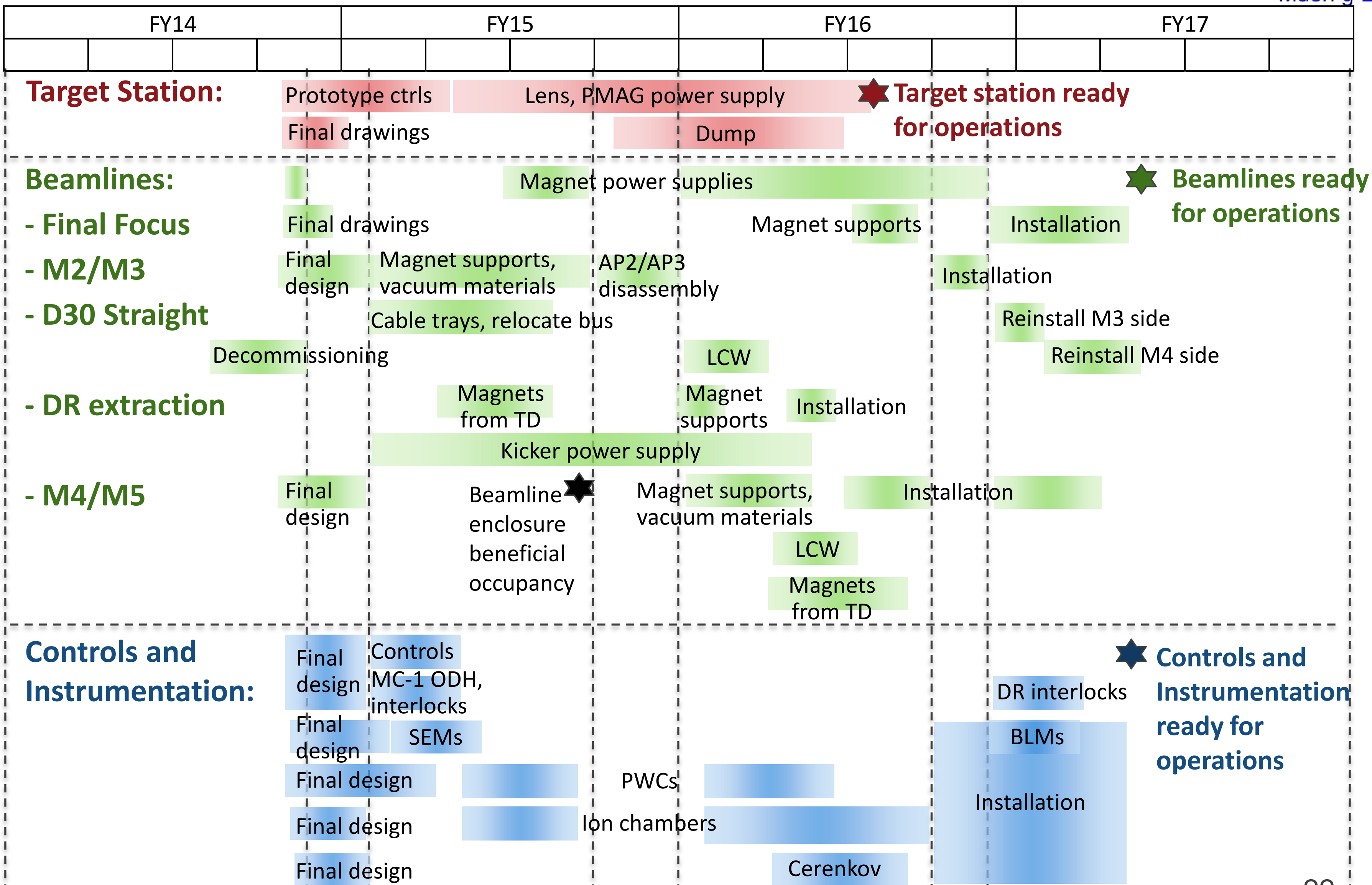
- Replacing the dump has never been performed. There will need to be careful planning with attention to radiological concerns. GM2-doc-1691 outline MARS estimates from dose rates on dump. Preliminary detailed beam dump removal procedure can be found in GM2-doc-2025

- Detailed procedures exist for handling components in the radioactive target vault, and the activation will be lower after years of not running beam than it was during antiproton production.

Quality Control and Assurance

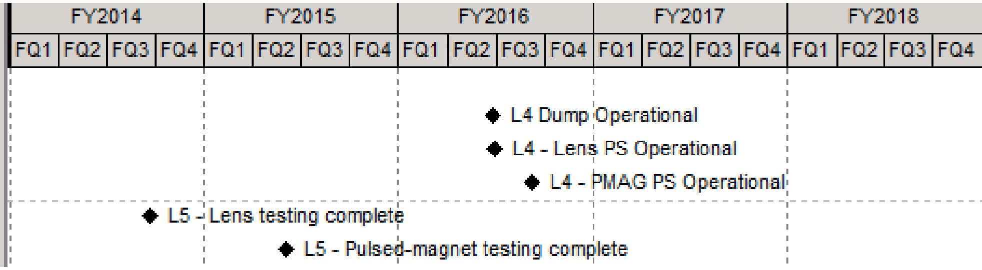
- The building of the pulsed power supplies and the beam dump have high engineering oversight in order to ensure quality to design.
- They utilize standard adherence to the Fermilab Engineering Manual.
- There is a good history of operating experience with similar of repurposed devices of purchasing quality components to ensure quality and predetermined performance. There is QA summary document of practices, policy and procedures in GM2-doc-2021
- There is a month of power supply conditioning and testing and beam dump testing at the end of the implementation phase in order to assure working order and g-2 performance.

Schedule


FY14
FY15
FY16
FY17
Target Station:
Prototype ctrls
Lens, PMAG power supply
Target station ready for operations
Final drawings
Dump
Beamlines:
Magnet power supplies
Beamlines ready for operations
- Final Focus
Final drawings
Magnet supports
Installation
- M2/M3
Final design
Magnet supports, vacuum materials
AP2/AP3 disassembly
Installation
- D30 Straight
Cable trays, relocate bus
Reinstall M3 side
Decommissioning
LCW
Reinstall M4 side
- DR extraction
Magnets from TD
Magnet supports
Installation
Kicker power supply
- M4/M5
Final design
Beamline enclosure beneficial occupancy
Magnet supports, vacuum materials
Installation
LCW
Magnets from TD
Controls and Instrumentation:
Final design
Controls MC-1 ODH, interlocks
DR interlocks
Controls and Instrumentation ready for operations
Final design
SEMs
BLMs
Final design
PWCs
Installation
Final design
Ion chambers
Final design
Cerenkov

Milestones

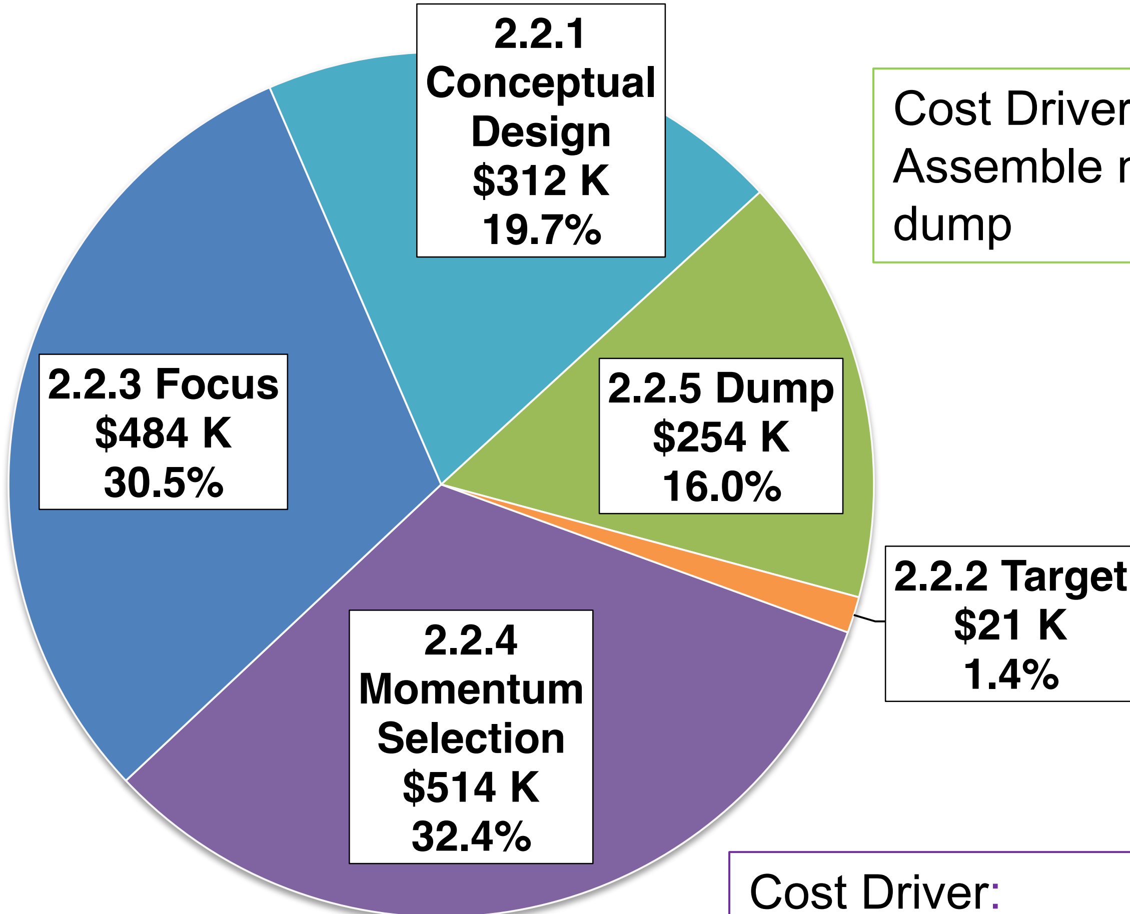
Name	Start	Finish
476-BaselineDOE-1.02.02 Target Station		
L4 Dump Operational		25-Mar-16
L4 - Lens PS Operational		30-Mar-16
L4 - PMAG PS Operational		07-Jun-16
L5 - Lens testing complete		19-Jun-14
L5 - Pulsed-magnet testing complete		02-Mar-15



Cost Distribution

DOE	Fermilab Labor	M&S	Non-FNAL Labor	Total
2.2 Target Station	Base ($K)	Base ($K)	Base ($K)	Base ($K)
2.2.1 Conceptual Design	293	19	0	312
2.2.2 Target	21	0	0	21
2.2.3 Focus	319	164	0	484
2.2.4 Momentum Selection	364	150	0	514
2.2.5 Dump	112	142	0	254
Grand Total	**1,110**	**475**	**0**	**1,585**

Cost Distribution

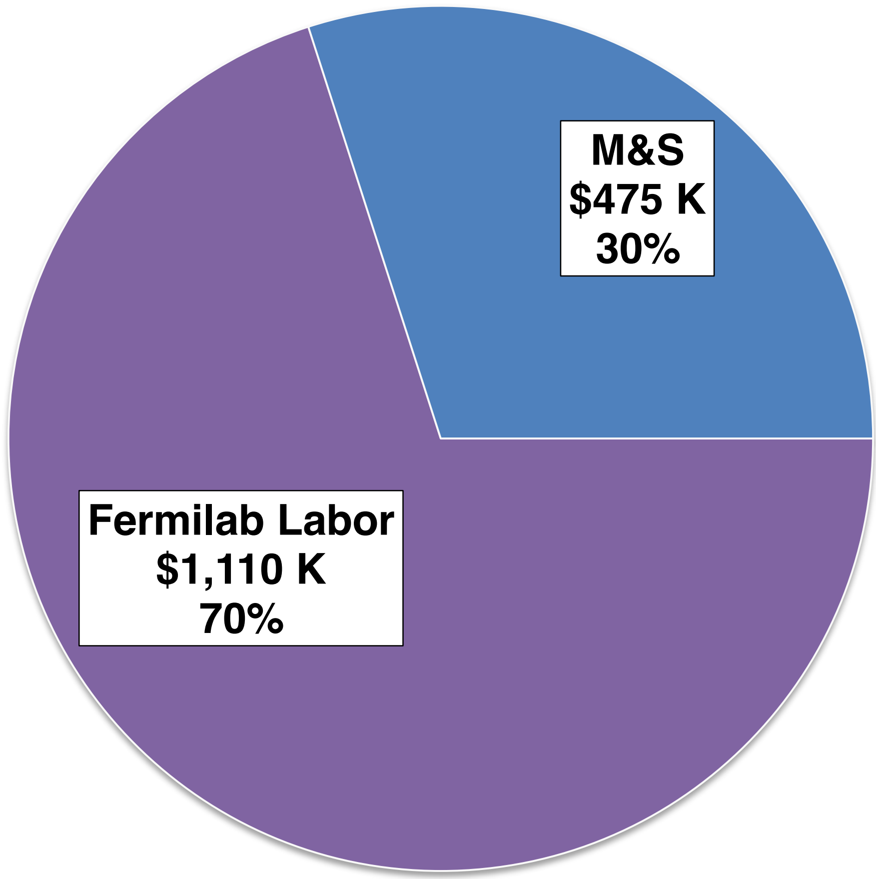


Cost Driver: Assemble new dump

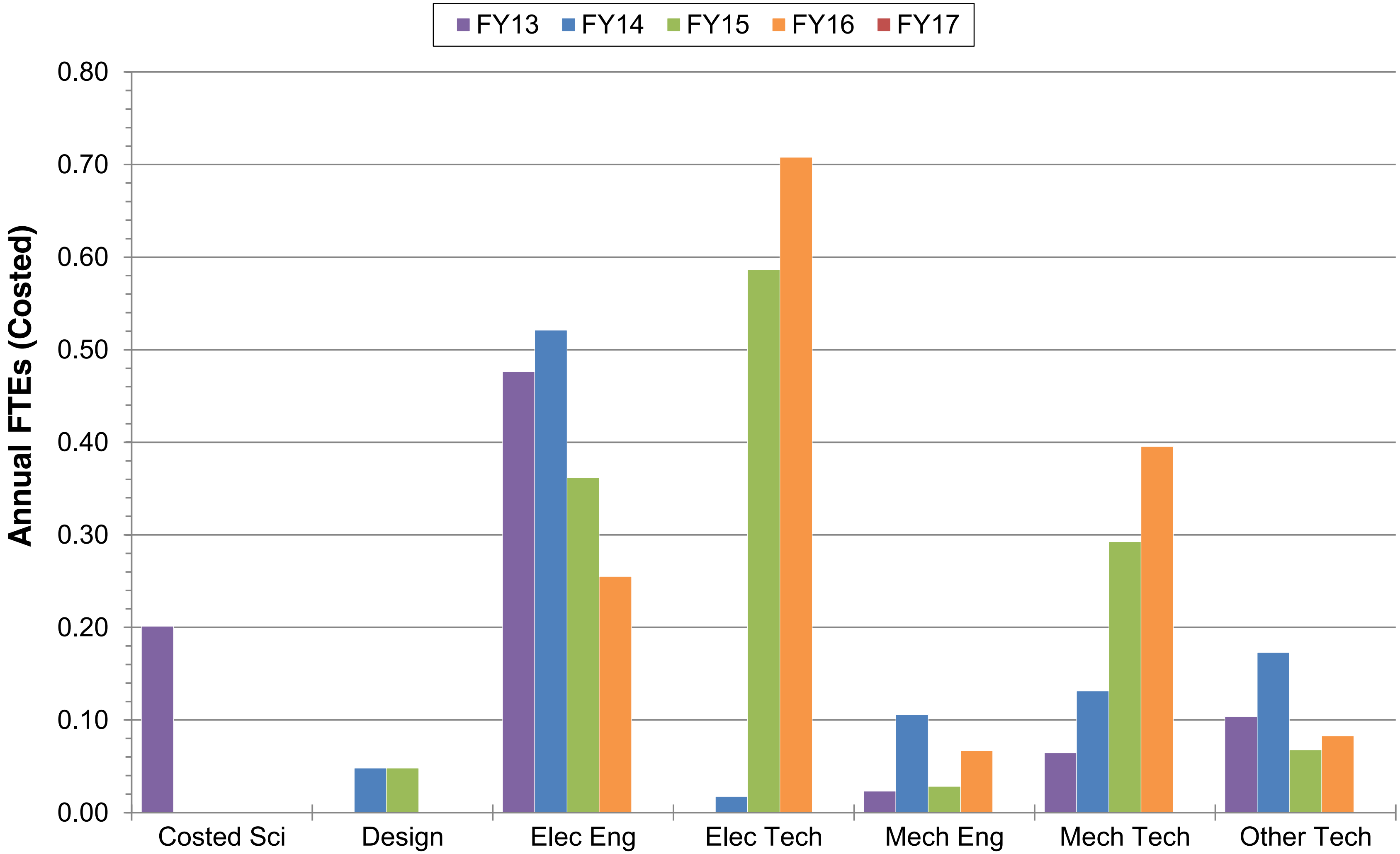
Cost Driver: Assemble and test power supply

Cost Driver: Assemble and test power supply

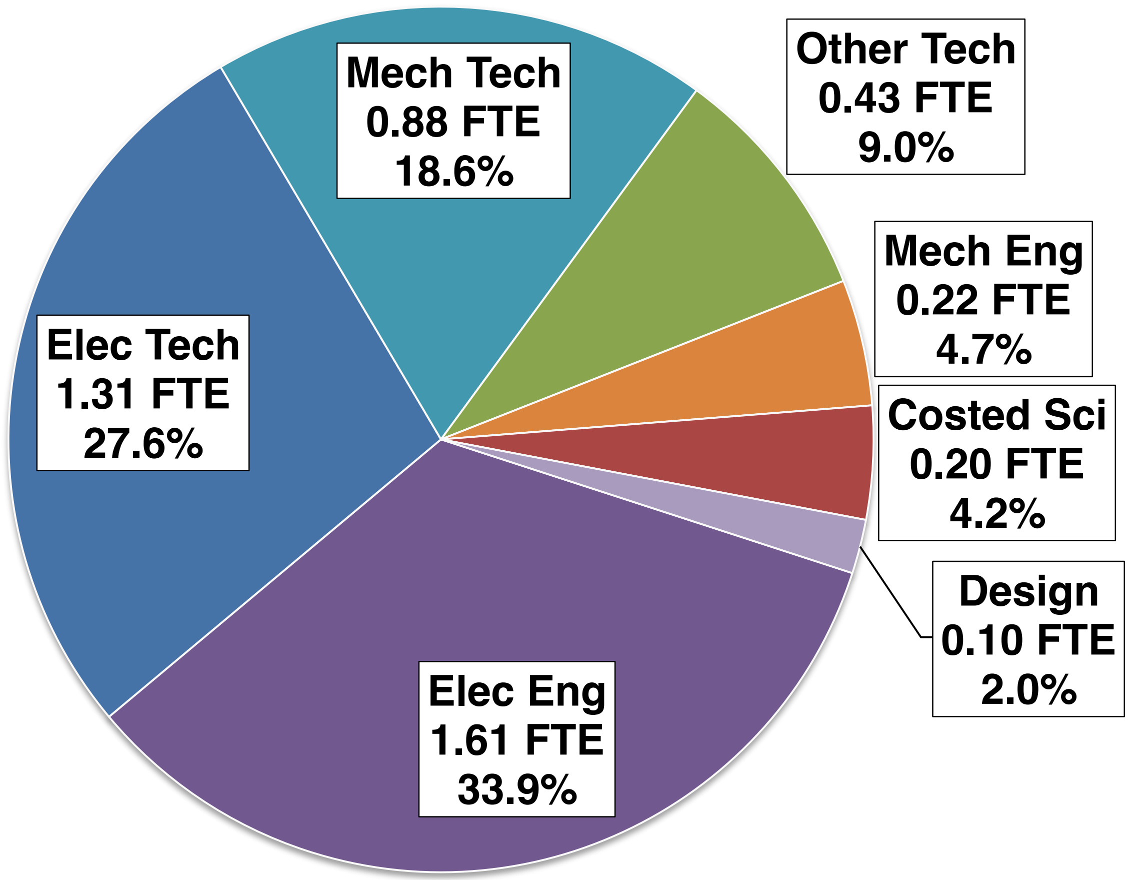
Resource Type



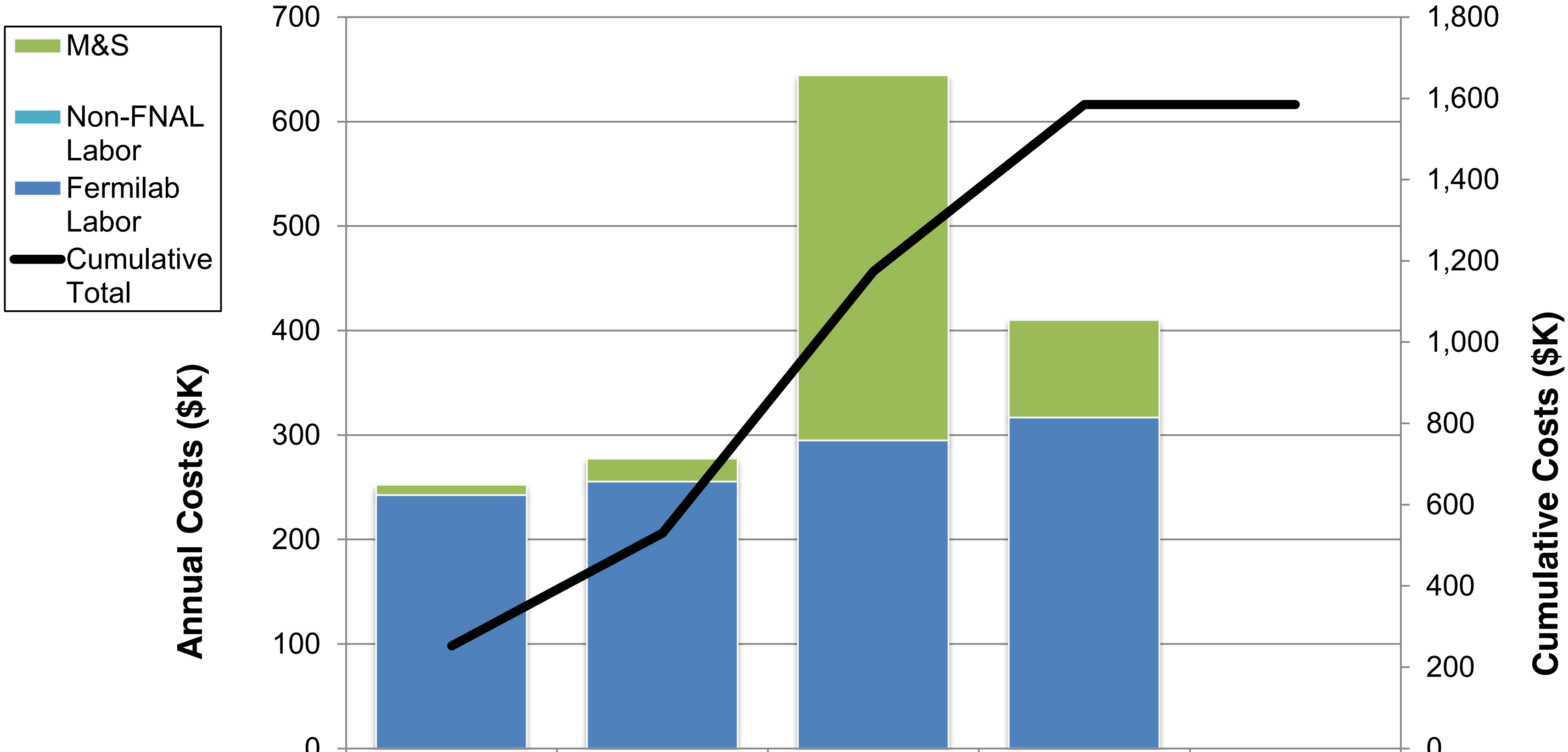
Costed FTEs by FY



Labor Resources by Type



Cost Profile by FY



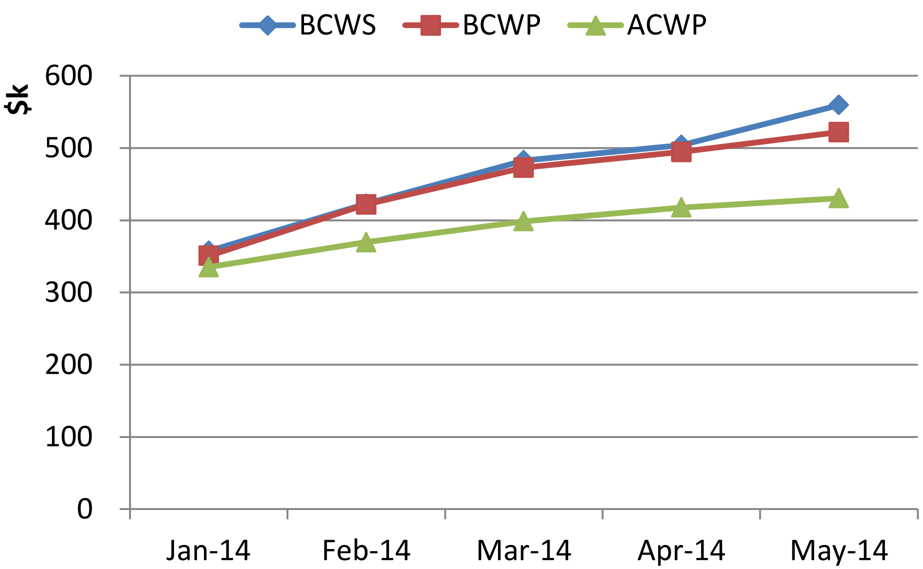
	FY13	FY14	FY15	FY16	FY17
M&S	$10 K	$22 K	$349 K	$93 K	$0 K
Non-FNAL Labor	$0 K	$0 K	$0 K	$0 K	$0 K
Fermilab Labor	$242 K	$256 K	$295 K	$317 K	$0 K
Cumulative Total	$253 K	$530 K	$1,174 K	$1,585 K	$1,585 K

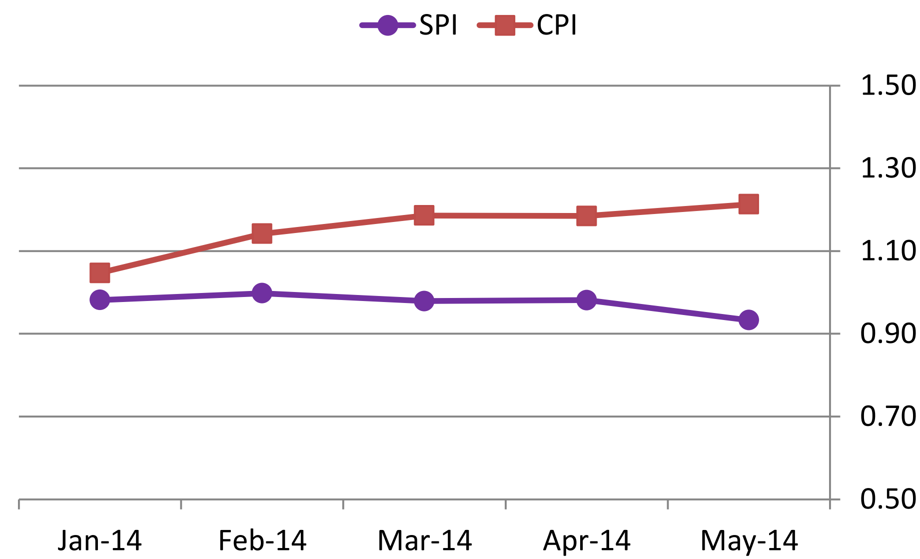
Estimate Uncertainty

DOE 2.2 Target Station	Performed	ETC (Scheduled - Performed)	Est. Uncertainty	% EU on ETC
2.2.1 Conceptual Design	311,660	(0)	0	0%
2.2.2 Target	21,488	0	0	0%
2.2.3 Focus	46,636	436,906	132,082	30%
2.2.4 Momentum Selection	27,166	486,819	146,046	30%
2.2.5 Dump	23,482	230,346	63,437	28%
Grand Total	**430,431**	**1,154,071**	**341,566**	**30%**

EVMS Since January – Target Station

This is L3 EVMS for the Target Station. Practicing since January 2014





- Using practice baseline from Dec 2013
- Target station work is under budget and slightly behind schedule as of May

Summary

Muon g-2

- This system accepts 8-GeV protons on target at the g-2 beam repetition rate and produces 3.1 GeV π^+

- The π^+ yield is expected to satisfy requirements for the number of μ^+ transported to the muon storage ring.

- The cost is $1.6M

- Cost drivers are the construction of 2 pulsed power supplies and the construction of a 80kW beam dump.